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Editorial

Professor Dr. Detlef Löhe

Professor Dr. Hans-Jörg Bauer

Energy constitutes a key factor in economic growth, social development, and the individual`s quality of life. However, the challenges of meeting increasing energy needs and mitigating climate change are global in scale. International collaboration in energy research is therefore crucial. The Energy Center of the Karlsruhe Institute of Technology (KIT), one of Europe's leading energy research institutions, conducts projects that are visible on an international level and cooperates with renowned partners all over the world. A high priority is given to research and innovation activities within the EU.

KIT participates in the European Energy Research Alliance (EERA), which aims to accelerate the development of energy technologies according to the European Strategic Energy Technology Plan (SET-Plan), and contributes to several EERA Joint Programmes, e. g. on energy storage and on materials for nuclear energy technology. Furthermore, KIT is a member of KIC InnoEnergy, a Knowledge and Innovation Community (KIC) created under the leadership of the European Institute of Innovation and Technology (EIT). As an alliance of top European players – companies, research institutes, universities, and business schools –, KIC InnoEnergy fosters the integration of education, technology, business, and entrepreneurship, and aims at establishing a sustainable energy system.

The EU energy research policy is based on the awareness that no single energy option has the capacity to fulfil all energy needs. Therefore, research and development should keep all options open to make future energy systems more efficient, safe, secure, affordable, and environment-friendly. Research at the KIT Energy Center is consistent with this position. In the current issue of EnergyNews, we focus on the international dimensions of KIT energy research.

We wish you an inspiring read!

Professor Dr. Detlef Löhe,
KIT Vice President
Research and Information

Professor Dr. Hans-Jörg Bauer,
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KIT Energy Center

A new concept in energy innovation

With the objective of becoming the leading engine of innovation and entrepreneurship in sustainable energy, the European company KIC InnoEnergy invests in research and education, commercialisation, and product development. These are essential to secure Europe's global competitiveness in energy technologies.

52 new ventures nurtured in the company's incubator, 458 students currently enrolled in the educational programmes, 40 patents filed: so far, the European company KIC InnoEnergy has made great achievements in its three work areas of Business Creation Services, Education, and Innovation Projects. KIC InnoEnergy was launched in May 2010 with the ambition to become the leading engine for innovation and entrepreneurship in sustainable energy. It is one of the first three Knowledge & Innovation Communities (KICs) supported by the European Institute of Innovation and Technology (EIT).

Incorporated as a company (Societas Europaea), KIC InnoEnergy works to transform ideas and knowledge into value. To achieve this, KIC InnoEnergy fosters the integration of education, technology, business, and entrepreneurship as the means to strengthen the culture of innovation. KIC InnoEnergy is committed to reducing costs in the energy value chain, increasing security, reducing CO_2 and other greenhouse gas emissions, and ensuring Europe's global competitiveness in energy technologies.

The technology roadmap that guides KIC InnoEnergy's operations with respect to technology innovation derives from the objectives of the Strategic Energy Technologies Plan (SET-Plan) of the European Commission. Accordingly, KIC InnoEnergy focuses on six thematic areas of sustainable energy: Clean Coal Technologies, Energy from Chemical Fuels, Energy Efficiency, Intelligent Energy-Efficient Residential Buildings and Cities, Renewables (wind energy, solar energy – solar thermal and photovoltaics –, wave and tidal energy), Smart Electric Grids and Electric Storage, and Sustainable Nuclear and Renewable Energy Convergence.

The shareholders of KIC InnoEnergy are among the top-ranked actors in the knowledge triangle of research, education, and business.

KIC InnoEnergy's financial goal is to become self-sustainable, i.e. to be independent of single-source funding. For this purpose alternative revenue streams are being built up. The company's business plan is delivered through six offices: Benelux, France, Germany, Iberia, Poland Plus, and Sweden. These form the access points to the company's European network of partners and to its offering of products and services. Karlsruhe is the centre of activities in Germany, with the headquarters located in the Karlsruhe Technology Park. Shareholders of KIC InnoEnergy Germany GmbH are the Karlsruhe Institute of Technology (KIT), the University of Stuttgart, EnBW, and Steinbeis Europa Zentrum. Further partners are Landesbank Baden-Württemberg and Fraunhofer ISI.

As a whole, the KIC InnoEnergy network comprises more than 150 partners. They are the top-ranked actors in the knowledge triangle of research, education, and business, and include industrial enterprises, research institutes, universities and business schools, representing every part of the energy value chain. Members of KIC InnoEnergy may be divided into two groups, depending on their contribution to the industrial plan: 27 shareholders and 125 associated and network part-

KIC InnoEnergy focuses on various thematic areas of sustainable energy.

ners. Together, the members are committed to a seven plus seven years industrial plan to mobilise 400 millions of euros annually in the run-rate.

In addition to the knowledge triangle, the concept of glocality – integrating global and local aspects – and a new type of private-public partnership make KIC InnoEnergy different: companies, universities, start-ups, entrepreneurs, and students engage in Europe-wide activities and take part in teams that span the continent. Through the expansive network of KIC InnoEnergy partners, they can reach almost any geographical location. As KIC InnoEnergy is managed as a business with a lean and flexible structure and profit-oriented but not dividend-oriented, a seamless interaction of SMEs, start-ups, and industry is possible. This results in both innovation activities and the generation of commercial revenues that can then be reinvested.

The work area of Business Creation Services includes the KIC InnoEnergy Highway® that provides the services entrepreneurs need to transform an idea or early venture into a successful business. KIC InnoEnergy actively works with entrepreneurs in four dimensions that are essential to success: technology, market, team, and finance. In the area of Education, KIC InnoEnergy offers excellent programmes in its MSc School and PhD School that combine a sound technical education in engineering with innovation, business, and entrepreneurship (IBE) activities. In KIC InnoEnergy Innovation Projects, all relevant players work together to develop a competitive product or service. The projects unite different players within the life cycle and value chain, consider the friction between the technology's push and the market's pull, and include continuous portfolio management.

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Capturing the complex context of change

The independent European Energy System Analysis Agency ESA² provides qualified decision support for governments, NGOs, and companies in areas relating to energy and environment policies and investments. ESA² combines well-known models with a concerted data base.

On the way towards a sustainable energy system major changes need to be realised. These include switching to low-carbon or carbon-free fuel sources, and improving the efficiency of energy conversion, transport, distribution, and use. However, the dominance of fossil fuels has shaped existing energy institutions and hampers the adoption of sustainability principles. Established industrial processes, transport, buildings, and urban infrastructure in general can only be replaced gradually by more energy-efficient alternatives. In many cases, decision makers in the energy sector lack reliable information to assess the benefits and drawbacks of their options in advance. To support sustainable decision making in energy systems, instruments are needed that allow for dynamic systems analysis, thereby considering the interactions between political, technical, and economic conditions and the behaviour of individual actors.

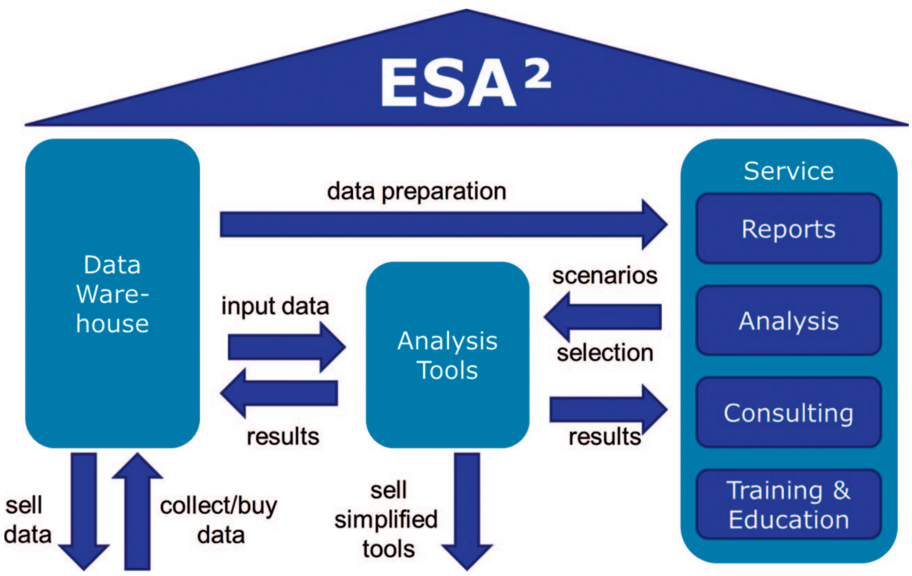
This is what ESA² provides. ESA² – short for "Energy System Analysis Agency" constitutes a platform to transfer scientific findings to society, politics, industries, and business on a European level. Supported by KIC InnoEnergy Germany, ESA² is an independent international agency that provides qualified decision support for public and private clients in areas related to energy and environment policies and investments. ESA² uses multiple systems-analysis-based tools to analyse complex scenarios with regard to strategic planning.

The uniqueness of the services provided consists in the large aggregation of energy-related information that can be analysed to provide decision support and in the use of a range of established models that can be selected and combined in the most suitable way to serve the specific demands of clients. Partners of ESA² are the following renowned European research institutions: University of Science and Technology (AGH), Krakow; Central Mining Institute (GIG), Katowice; European Institute for Energy Research (EIFER), Karlsruhe; Fraunhofer Institute for Systems and Innovation Research (FhG-ISI), Karlsruhe; Karlsruhe Institute of Technology (KIT); Dresden University of Technology, University of Stuttgart; Royal Institute of Technology (KTH), Stockholm; VITO, Mol. The project management lies with the Institute for Industrial Production (IIP) of KIT. Also involved in ESA² are the Institute for Technology Assessment and Systems Analysis (ITAS) and the Institute for Applied Computer Science (IAI) of KIT. In 2014, the project will spin off into a new company.

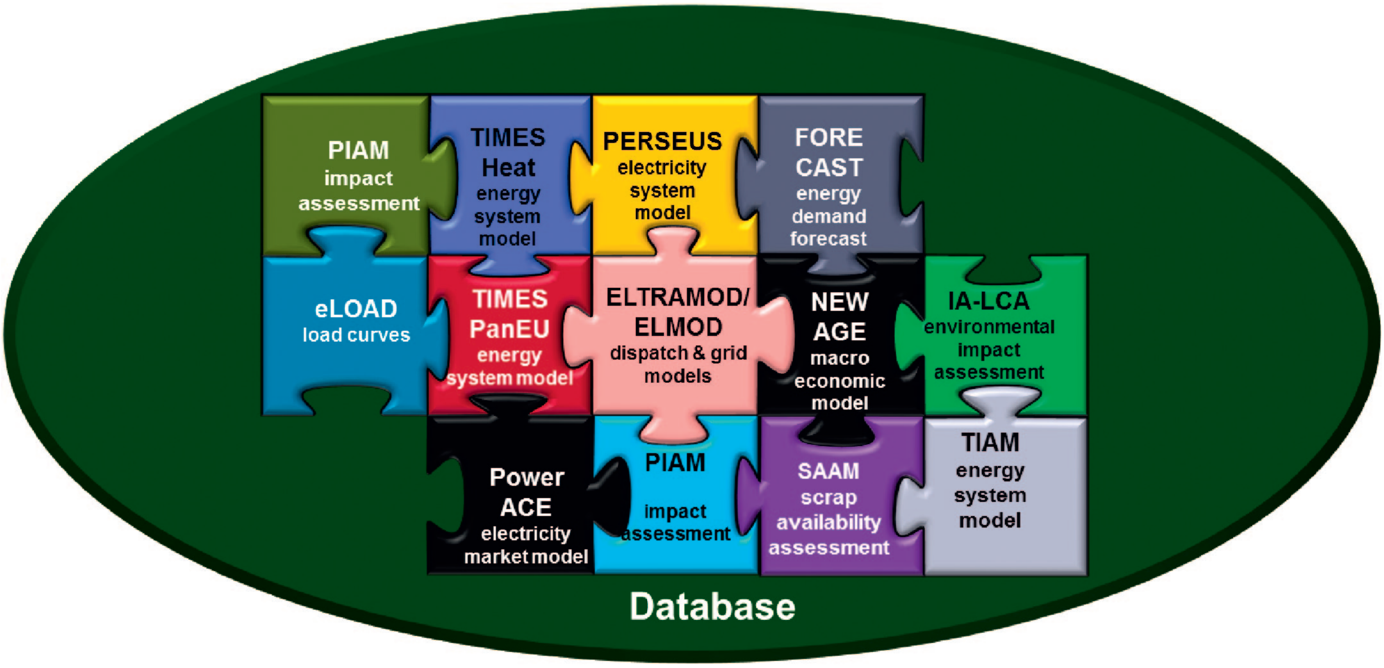
The overarching aim of ESA² is to provide in-depth studies on the economic and environmental impacts of energy and environment policies and investments on economies, sectors, and companies, thereby considering the interconnections and dependencies within the system of energy supply and demand as well as the connection to other socio-technical systems, e.g. mobility, and the acceptance in society. The corresponding products and services of ESA² are assigned to three clusters: services, analysis tools, and a data warehouse.

Services of ESA² include reports and consulting. Reports provide detailed and highly sophisticated information on specific topics. The latest information focuses on the EU Energy Roadmap 2050 and on energy-intensive industries, e. g. the iron and steel sector. One distinguishing feature of all ESA² reports is a close connection between model-based and non-model-based analyses. Consulting comprises the following services: monitoring of technological development, assessment of political framework conditions, identification of market potentials for new technologies, addressing of the barriers in markets for new technologies and products, processing of information related to market behaviour, assessment of environmental impacts, and the creation of a neutral platform for dialogue among stakeholders.

Energy systems analysis is based on the use of mathematical software models, which serve as an appropriate platform to analyse complex issues. All partners of ESA² possess extensive experience in using models under different national and international conditions and are continuously working on the further development of the models. Some of these models are already quite well-



Products and services of ESA².



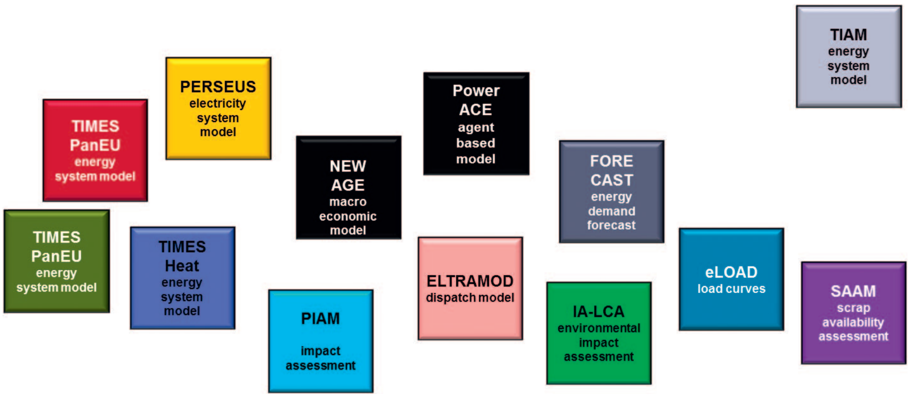
The new approach of ESA²: a flexible tool kit of well-known models and approaches linked to a common data base.

established in scientific as well as political and economic contexts. As a general rule, one single model cannot cover all aspects of an energy system or all implications of specific policies. The innovative approach of ESA² is to combine the strengths of the existing models, thus enhancing the potential of individual instruments, and to allow for new and more comprehensive methods of analysis.

ESA² is able to apply a broad range of established systems analysis methods. These include: optimising energy and material flow models for technological mapping of the energy sector, simulation models to study causal relationships between individual components of a real system, game-theoretic models to analyse market power in oligopolistic markets or market structures, and environmental assessment using life-cycle assessment (LCA) and multi-criteria analysis (MCA). In addition, the partners of ESA² have the know-how to perform comprehensive and fundamental changes or new developments in model structure.

The results of an analysis do not only depend on the chosen methodology, but also on the quality of the data used. Another powerful advantage of ESA² is to couple already established models with a consistent data base. In the simplest form, this is ensured by transferring the results of one model via an interface to another model. Furthermore, there are plans to develop new integrated model approaches based on separately existing models. Thus ESA² creates a flexible tool kit to serve the specific demands of clients.

Robert Kunze
Witold-Roger Poganietz



Models used by ESA² partners (currently uncoupled).

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Efficient chemicals and fuel production from biomass

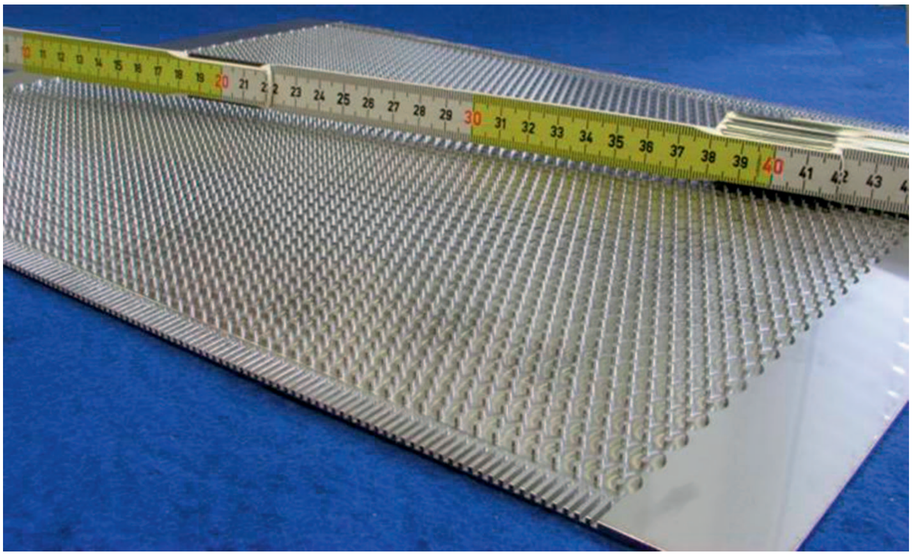
The SynCon project ("Novel synthesis process concepts for efficient chemicals/ fuel production from biomass"), a KIC InnoEnergy innovation project, addresses selected process routes for the conversion of biomass into high-value chemicals and fuels for application in small-scale as well as large-scale facilities. Researchers develop new methods for processing biomass as well as new reactor technologies with a high potential for process optimisation. The overall aim is to enhance efficiency.

CyclOx® (Cyclic Oxygenates), a product of SynCon, is a class of additives which can be derived from lignin, a byproduct of the paper industry. The combination of a cyclic structure and onboard oxygen improves the fuel-oxygen mixing process before and during combustion and suppresses the formation of soot. On the average, addition of ten per cent CyclOx® to diesel fuel results in a reduction of soot emissions by 50 per cent. CyclOx® can be added to both petrol and diesel fuel.

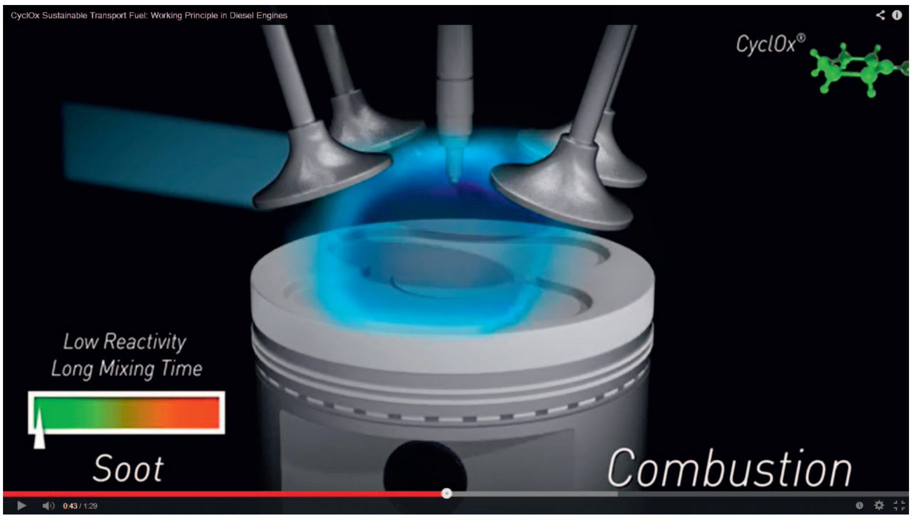
Another innovative product of SynCon is a compact micro-structured reactor that allows for the energy-efficient conversion of synthesis gas into diesel fuel. Synthesis gas is a mixture of hydrogen and carbon monoxide and can be produced from any kind of biomass. As the structured reactor can transport heat more efficiently, generated process heat – 15 to 20 per cent of the energy content of the synthesis gas – can be utilised. Furthermore, the construction of the structured reactor minimises the required space by the factor of 80 compared to a conventional reactor and reduces weight by the factor of two. Hence, container-based facilities for the storage of biomass can be constructed without a connection to the natural gas grid or the adaption of biogas quality to natural gas quality.

Partners of the SynCon project are Grenoble INP (France), GIG (Poland), KIT (Germany), KTH (Sweden), Statoil (Norway), Technische Universiteit Eindhoven (The Netherlands), Uppsala Universitet (Sweden), and Progression Industry (The Netherlands).

Peter Pfeifer



A structured reaction plate designed for a reactor that produces synthetic diesel fuel.



Clean combustion with CyclOx®.

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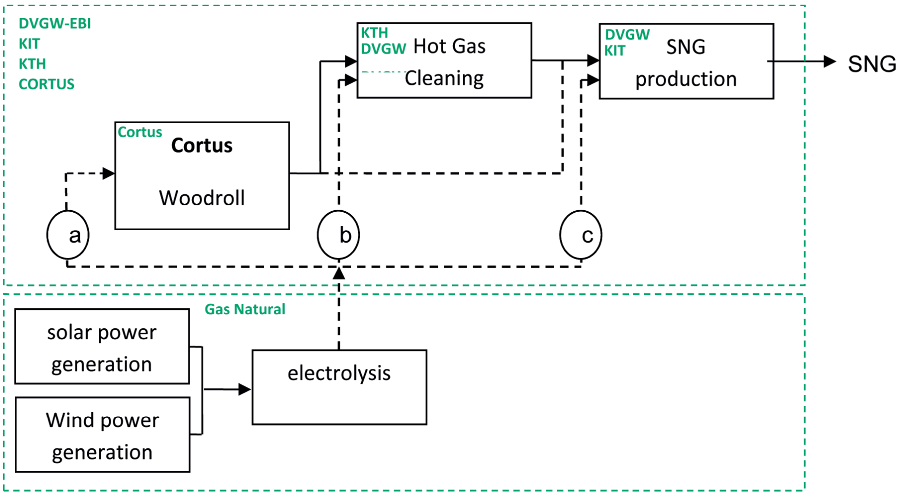
An optimised SNG production route

The production of high value synthetic natural gas (SNG) from regenerative sources like biomass can lower the dependency of Europe on fossil energy resources from non-European countries. Furthermore, the conversion of electrical energy to SNG – the so-called power-to-gas process – can help to cover the rising demand for energy storage in regenerative energy systems. State-of-the-art processes for SNG production, however, suffer from poor efficiency and low process reliability due to inadequate gas cleaning and methanation processes.

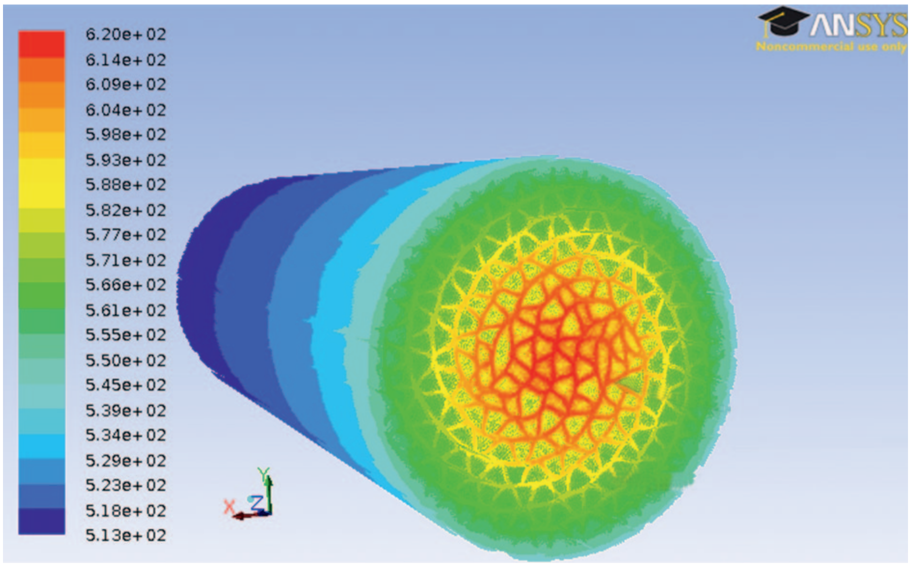
Within the framework of the KIC InnoEnergy innovation project DemoSNG ("Demonstration of improved catalysts and reactor designs for the production of SNG from biomass via gasification"), researchers develop a novel process chain for upgrading raw gas to synthetic gas quality. This process chain will increase the efficiency by converting the highly calorific tar components into additional clean synthesis gas and at the same time enhance synthetic gas quality by improving the sulphur removal process. Furthermore, the researchers demonstrate the technical feasibility of the conversion of electrical energy into SNG by embedding hydrogen generation in a biomass gasification plant with subsequent SNG synthesis. A specific methanation reactor design for improved CO conversion and heat extraction will simplify the process chain in order to optimise SNG production for small decentralised SNG plants.

DemoSNG belongs to the KIC InnoEnergy thematic field "Energy from chemical fuels" and has involved four partners: KTH (Sweden), Cortus (Sweden), KIT (Germany), and Gas Natural Fenosa (Spain). An already exting biomass gasification plant in Köping (Sweden) provides a side stream for long-term demonstration tests. Researchers of the DVGW-Forschungsstelle at the Engler-Bunte-Institut of KIT work on the process chain for the upgrading of raw gas to synthetic gas quality as well as on new catalysts for methanation in newly designed reactors. Based on the results of DemoSNG, academic and industrial partners will develop the following new innovative products and services: a reduced basic design package for the hot gas cleaning process, a computational fluid dynamics tool for methanation reactor design, and an integrated power-to-gas/SNG production process.

Dominic Buchholz



The structure of DemoSNG, a KIC InnoEnergy innovation project.



Methanation in metallic honeycomb catalysts (Temperature T in K).

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Biocoal for gasification

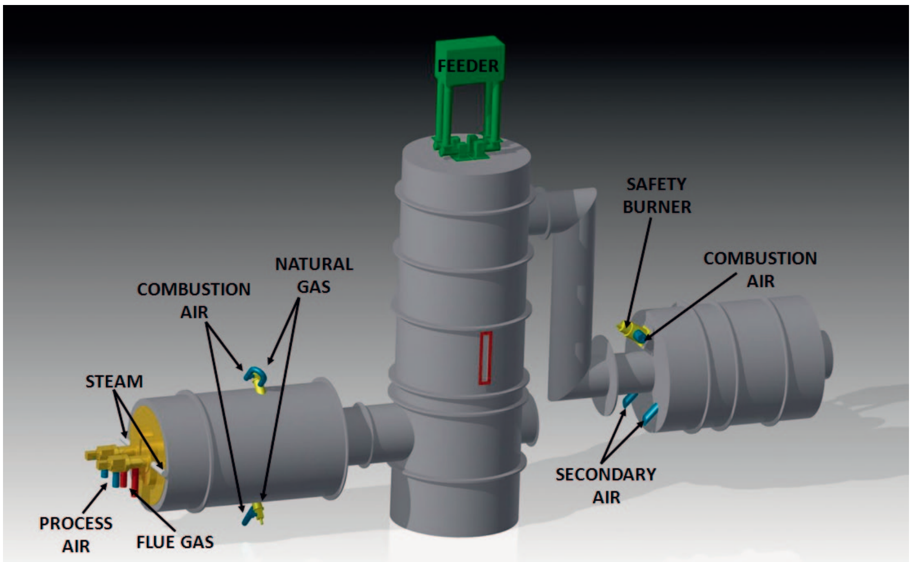
Gasification is an appropriate tool to produce power from a wide variety of fuels ranging from fossils like coal or anthracite to different kinds of biomass. Regarding biomass, the feedstock mainly used for gasification is woody biomass, but wood resources in Europe are limited and most of them are already used. Hydrothermal carbonisation (HTC) converts wet biomass, e.g. digestate, green wastes from municipalities, or wet wastes from food industry, into a dry solid fuel. This so-called biocoal is a suitable fuel for gasification.

In the KIC InnoEnergy innovation project xGaTE (EXtended Gasification Technologies) researchers evaluate different process options for the gasification of various kinds of biomass and investigate their potential to improve the gasification process and to increase fuel flexibility.

They test different types of solid biomass and biocoal with regard to their suitability for high-temperature agent gasification (HTAG), a process developed at KTH (Sweden), as well as a bubbling fluidised-bed gasifier provided by EQTEC (Spain). In order to extend the range of suitable feedstock materials to also cover humid or wet biomass, HTC and the gasifier – either HTAG or the EQTEC gasifier – shall be coupled in a combined process. Thus both technologies can considerably increase the scope and economic efficiency of gasification.

Using biocoal as an intermediate product for gasification, the spectrum of biomass suitable for gasification is broadened to also cover wet and green biomass. Furthermore, biocoal provides a more homogeneous fuel, therefore increasing efficiency and decreasing costs. The syngas is expected to have a low tar content, which substantially decreases the gas cleaning costs and allows for the utilisation of a gas engine as an economically attractive solution for small-scale distributed energy production. The gasifier provides steam for the HTC technology in cases where waste heat is not available, thus extending the application area of HTC. The combination of HTC and HTAG is expected to provide an energy-efficient and economically viable solution for areas with abundant wet and green biomass.

HTC (hydrothermal carbonisation) pilot plant of AVA-CO2 (Germany).



Schematic diagram of the HTAG (high-temperature agent gasifier) of KTH (Sweden).

The xGaTe project has seven partners: AVA-CO2 (Switzerland/Germany) makes available own HTC pilot and demonstration plants. EQTEC (Spain) provides a pilot-scale fluidised-bed gasifier that is currently operated with biomass and will be tested with biocoal. KTH (Sweden) has developed the high-temperature agent gasifier (HTAG). The feed system will be modified such that different kinds of biomass and biocoal can be fed into the gasifier. In addition, KTH develops a simulation tool for the HTAG. The University of Stuttgart tests different qualities of biocoal with regard to their suitability for gasification. KIT evaluates the kinetic data necessary for the simulation of the gasification process, which helps to optimise the quality of biocoal with regard to its use in the HTAG. Furthermore, KIT tests biocoal in a pilot-scale entrained flow gasifier (REGA). EIFER/EdF studies biomass gasification in the last 20 years in order to compare different biomass-based energy production chains. Within the xGaTe project, EIFER evaluates the overall process chain and system interaction using the ASPEN software. Steinbeis Europa Zentrum performs the market analysis and identifies business opportunities.

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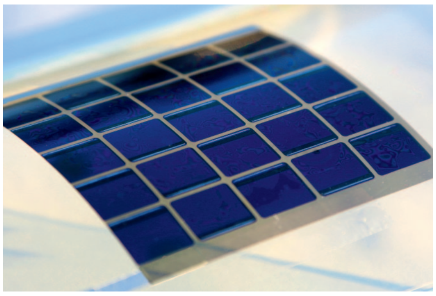
Enhancing the long-term stability of organic solar modules

The power conversion efficiency of organic solar cells recently exceeded ten per cent, rendering this young technology interesting for consumer products and OEM applications. In order to employ organic photovoltaics for large-scale power harvesting, however, the stability of the solar modules needs to be improved significantly compared to the present state of the art. The multi-disciplinary KIC InnoEnergy innovation project EnThiPV ("Encapsulation of flexible Thin film PV devices") investigated ways to enhance the long-term stability of organic solar modules by improving the device encapsulation through new oxygen and moisture barriers.

As future organic solar cells will be printed by roll-to-roll processes onto plastic foils that do not exhibit any intrinsic barrier properties, these barriers will be of pivotal importance for the commercialisation of organic solar cells. Consequently, the EnThiPV project was an essential part of the organic solar cell research activities at KIT and of the respective project portfolio. New barrier foils were fabricated by the project partners Amcor and Tecnalia. The barrier properties were assessed by the project partner CEA that developed a new measurement technique for thin-film barriers.



An organic solar module integrated on a curved surface.

KIT, home of one of the leading research groups in the area of printable organic solar cells, was in charge of device fabrication, encapsulation as well as enhanced life-time and stability investigations. Work was performed by the Printed Electronics Group of Professor Uli Lemmer, which is situated at the Innovation Lab in Heidelberg, and the early career research group on organic solar cells of Dr. Alexander Colsmann at the Light Technology Institute (LTI). KIT, Tecnalia and CEA investigated the impact of the integrated oxygen and moisture barriers on the performance of the organic solar cell device and benchmarked the barriers versus commercially available solutions.

The multi-national project consortium comprised leading companies and research centres all along the value chain: CEA (France), Disa Solar (France), Vinci Technologies (France), Amcor (France/Switzerland), Tecnalia (Spain), IREC (Spain), UPC (Spain), ESADE (Spain), and KIT (Germany).The EnThiPV project marked the beginning of a fruitful cross-border collaboration in particular between KIT and CEA. The success of the EnThiPV project allowed for the submission of a new project proposal under the Seventh Framework Programme of the EU on new materials for organic solar cells. Recently, this proposal was approved of by the European Commission. It will start in January 2014.

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Solutions for small-scale bioenergy power plants

In the close future, bioenergy will play a key role in power production. More than four additional GW of electrical power (el) are to be installed in Europe in the next five years. One of the major challenges arises from a fragmentation of the bioenergy market due to the complexity of matching diverse feedstocks, technologies, and applications. Despite market fragmentation, solid biomass is the major fuel used for bioenergy today, and combustion technologies have a share of more than 90 per cent in the total market.

Smalls-scale power range (2.5 – 6 MWel) is expected to reach a high share in the newly installed base capacity. These plants can improve the use of local biomass in order to meet decentralised energy needs and reduce environmental impacts. However, the main technical challenge is to provide an efficient solution that takes the specific properties of biomass fuel into account and, at the same time, is economically competitive. In addition, delivery time is a key factor to reduce the time to market.

A solution whose modularisation decreases capital costs, offers the flexibility to burn diverse woody biomass, and shortens delivery time would be highly useful for developing this market. Therefore, the KIC InnoEnergy innovation project AdCUB ("Advanced Combustion Unit for Biomass") focuses on innovations related to the development of a multi-fuel modular power plant. AdCUB is financed by KIC InnoEnergy France.

First results show that capital costs may be reduced by up to 20 per cent and delivery time could be shortened by at least six months. The results of a conceptual design phase suggest that the following innovations would be highly advantageous: optimised definition of thermodynamic cycles, power plant redesign-to-cost, integration of a low-cost boiler solution, and development of a virtual instrumentation and control (I&C) platform for a biomass power plant.

The following partners are involved in the AdCUB project: AREVA, CEA (France), and KIT (Germany). AREVA is the coordinator of the project and is in charge of the project follow-up (quality, planning, and costs). Furthermore, AREVA is responsible for product definition and business analysis as well as for the conception of the modular small-scale biomass-based combined heat and power (CHP) plant.

CEA is responsible for the feedstock characterisation, and for the "multi-fuel acceptance" definition through state-of-the-art pre-treatment and fuel handling systems. During the design phase, CEA supports AREVA as regards the European standards to be observed in product definition. In addition, CEA will contribute its competence in fuel feeding and refractory for the boiler design.

KIT is in charge of biomass combustion characterisation for the utilisation in grate combustion systems. The tools for the characterisation of the combustion behaviour are a fixed-bed reactor with a mathematical model to transfer the results to continuous grate systems and a grate test bench for the validation of these results. Also tests in the pilot grate facility TAMARA are used to validate the mathematical model. As regards the design of the solution, KIT will be involved in the thermodynamic definition as well as in the grate and boiler design.

Florian Castagno (AREVA)
Hans-Joachim Gehrmann (KIT)
Marine Peyrot (CEA)

The TAMARA pilot plant for grate combustion at KIT: view into the combustion chamber.

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An intelligent system for monitoring radiation levels

I_SMART project workshop in Cadarache in 2012.

The present and future competitiveness of nuclear technology depends on the optimisation of accurate and predictive knowledge of the nuclear reactor core behaviour and radiation monitoring in nuclear environment. More efficient instrumentation optimises reactor operation, extends the service life, and reduces operating costs. Furthermore, nuclear safety is enhanced by advanced instrumentation and measurement methods. The new generation of material testing research reactors (MTRs), like the international Jules Horowitz Reactor under construction on the Cadarache site of CEA, as well as the fusion reactor ITER, also under construction at Cadarache, will need a complete new generation of on-line instrumentation and innovative measurement methods.

In the KIC InnoEnergy innovation project I_SMART ("Innovative Sensor for Material Ageing and Radiation Testing"), researchers explore the opportunities of new detector/sensor technologies coupled with ad hoc electronic devices, signal analysis, and data acquisition. Presently, the on-line selective and simultaneous detection of both fast and thermal neutron flux and high-energy gamma flux poses a challenge for experimental nuclear reactors, nuclear power reactors, nuclear fuel cycle analysis and management, safeguards, and medical applications like neutron capture therapy of cancer. Hence, there is a growing need for innovative advanced smart detection systems.

The European I_SMART project suggests the use of silicon carbide (SiC) technology as a platform to build an intelligent system for monitoring radiation levels. SiC electronics complies with the demands of radiation hardness and high-temperature operation. The researchers explore and develop a specifically strengthened SiC layer which shall then be adapted to the targeted application. The project takes advantage of the European research infrastructure such as research reactors (BR-1 of SCK·CEN Mol), intense bremsstrahlung sources (CEA Cadarache) as well as 14 MeV neutron generators of Schlumberger (Clamart) and Dresden University of Technology (TUD-NG) for testing the devices under development. The irradiation tests are coordinated by KIT and SCK·CEN. KIT provides also the access to the TUD-NG facility.

KIT is strongly involved in the European fusion research programme. The Institute for Neutron Physics and Reactor Technology (INR), in particular, works on the development of neutronics instrumentation for the so-called Test Blanket Modules of the fusion reactor ITER. They are part of two tritium breeding systems based on a liquid and a solid breeder concept which will be tested in ITER. Silicon carbide neutron detectors are expected to operate during the low fusion power phases of ITER and provide valuable experimental data on neutron fluxes and tritium production rates. These data will be utilised to check radiation transport codes and nuclear data used for designing fusion reactor breeding blankets. The data will also provide essential information on the performance of the two European breeding blanket concepts.

I_SMART is funded by the French National Research Agency ANR and executed by the following partners: Grenoble INP (France), IM2NP (France), CEA (France), KTH (Sweden), University of Oslo (Norway), AGH Krakow (Poland), SCK·CEN Mol (Belgium), KIT (Germany), Schlumberger (France) and AREVA (France).

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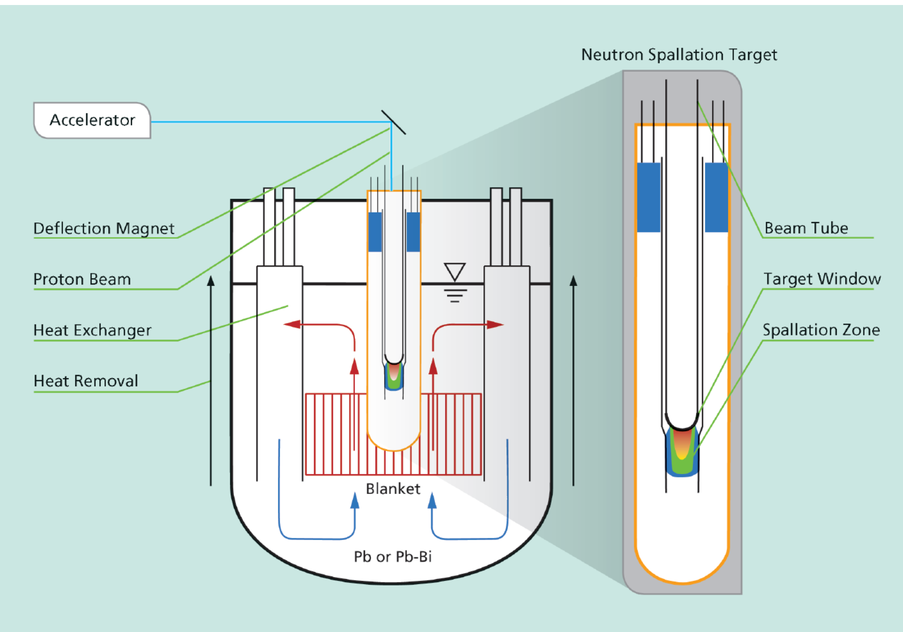
High-performance materials for low-carbon energy technologies

KIT coordinates the Joint Programme on Nuclear Materials within the European Energy Research Alliance. Potential innovations in nuclear energy technology are closely related to the development of new materials.

The European Strategic Energy Technology Plan (SET-Plan) is designed to enable the implementation of energy technologies that will mitigate climate changes due to greenhouse gas emissions. According to the SET-Plan, the following key objectives are to be reached by the year 2020 in Europe: a 20 per cent reduction of carbon dioxide emissions, a 20 per cent share of energy from renewable sources, and a 20 per cent reduction in the use of primary energy. Even more ambitious goals have been defined for the year 2050.

These objectives can be achieved through a balanced energy mix meeting the energy demand of the European population without possibly endangering social, financial, and environmental wealth. The SET-Plan objectives are pursued through the organisation of dedicated research and development (R&D) programmes as well as the implementation of industrial initiatives. Dedicated research is organised within the European Energy Research Alliance (EERA), which aims to accelerate the development of new energy technologies in Europe through improved coordination and cooperation and to establish long-term relationships.

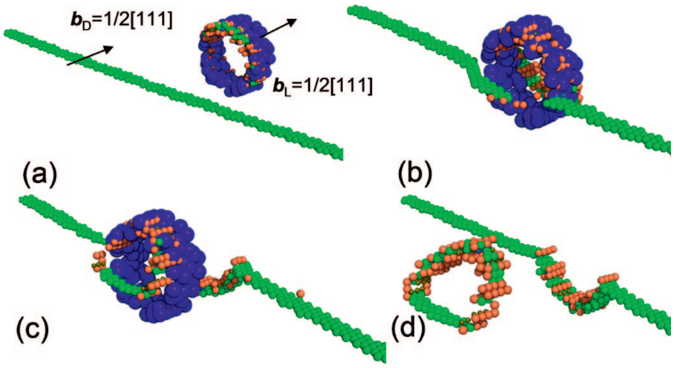
Together with technology platforms and industrial initiatives, EERA has identified the most promising energy technologies that fulfil the criteria defined by the SET-Plan, e.g. wind energy, solar energy (photovoltaics and concentrated solar power), geothermal energy, biomass energy, smart cities, and smart grids. Nuclear energy is as well covered by the SET-Plan and EERA. Potential innovations in nuclear energy technology are closely related to the development of new materials. In fact, the availability of high-performance structural and functional materials is considered to be crucial to innovation and potential breakthrough achievements for efficient low-carbon energy technologies in the future.



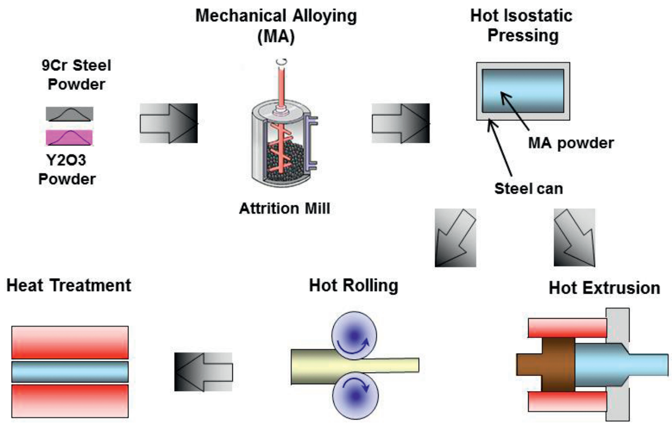
Schematic representation of a high-level waste transmutation system. This system is designed to host uranium-free fuel and it is cooled with liquid lead or lead-bismuth eutectic.

The EERA Joint Programme on Nuclear Materials (JPNM), coordinated by KIT, addresses key issues within the main research topics identified. These are: material development and screening; theoretical and experimental characterisation and qualification/validation; fabrication issues (e.g. welding, joining); pre-normative research. The overarching goal is to provide appropriate nuclear materials which are able to withstand the conditions and fulfil the requirements foreseen for Generation IV nuclear reactors and for nuclear waste transmutation systems. Another goal is to reach and to keep the highest excellence in materials science, both in the experimental and "first principles" modelling approaches, through the coordinated programmatic approach of leading European research associations. The first milestone for JPNM will be the implementation of well-qualified materials in the facilities that will be built under the European Sustainable Nuclear Industrial Initiative (ESNII), a further essential pillar of the SET-Plan in the area of nuclear energy technology. ESNII constitutes an integral part of the roadmap for the development of Generation IV nuclear reactors and nuclear waste transmutation systems.

Generation IV reactors and transmutation systems are innovative reactors developed in order to keep safety standards at least comparable to those of Generation III reactors, with other key objectives being the preservation of resources and the reduction of the high-level nuclear waste. These objectives can be achieved through the use of a high-energy neutron spectrum within reactor systems that operates with innovative fuels at high temperatures and with innovative coolant technologies, such as liquid metals (e.g. lead and lead alloys, sodium) or gas (e.g. helium). The materials suited for these conditions should exhibit a high mechanical and thermal strength as well as high corrosion and irradiation resistance. Promising materials that could cope with these conditions and accommodate the innovative fuels are oxide dispersed strengthened steels and composite materials, such as silicon carbide fiber reinforced silicon carbide composites (SiCf/SiC). Moreover, to increase corrosion resistance of the material, appropriate



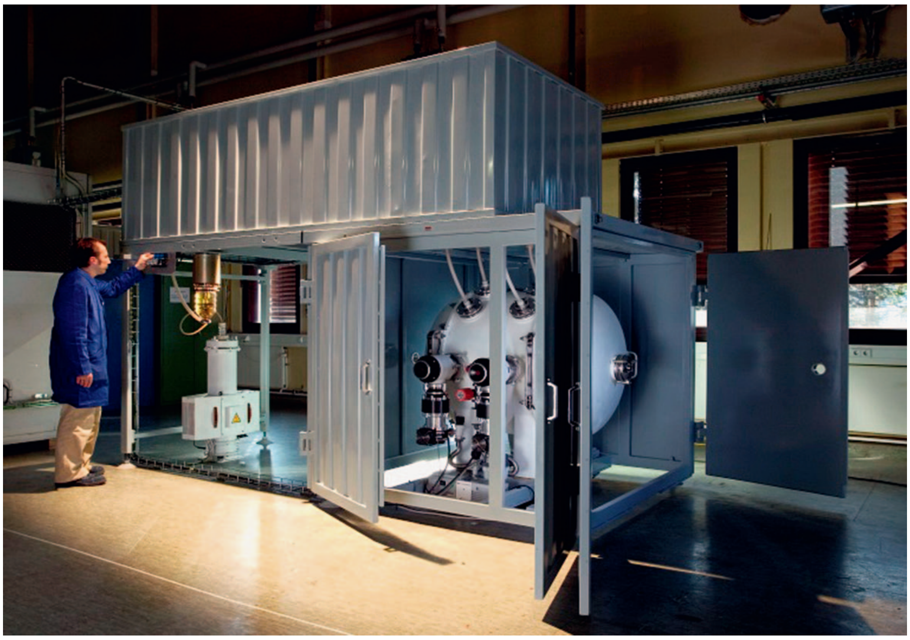
Simulation of the mechanism of interaction between an edge dislocation and a chromium-enriched loop. The simulation is used to describe hardening and embrittlement effects that can occur on irradiated materials. (Dr. D. Terentyev, SCK-CEN)



Scheme of the fabrication of oxide dispersion-strengthened alloys (ODS) by means of the powder metallurgy method. These materials are tested for their suitability in Generation IV reactors and transmutation systems. (Rainer Lindau, IAM, KIT)

protection systems can be developed. A promising corrosion protection system is the deposition of a coating with a spray technique and a post-deposition treatment with a pulsed electron beam.

Finally, the understanding of phenomena occurring on materials when they are subjected to thermal and irradiation fields is investigated within JPNM in order to support and accelerate the development and qualification of these innovative materials. Physical models are validated by dedicated model experiments, in which advanced investigation techniques are used, e.g. small angle neutron scattering, positron annihilation spectroscopy, atom probe tomography, and transmission electron microscopy. Parallel to these developments, JPNM addresses the development and qualification of innovative fuels for Generation IV reactors and transmutation systems. Innovative in this area is the fabrication of uranium-free fuel with a high content of actinides, such as neptunium, americium and curium. This class of fuels is specifically developed for transmutation purposes. The fuel development programme therefore focuses on fabrication and qualification items as well as on fundamental science studies to address fuel behaviour under relevant conditions.



Pulsed Electron Beam Facility (GESA), a KIT facility for the optimisation of corrosion protection barriers. (Professor Georg Müller IHM, KIT)

At present, JPNM has 19 partners and 13 associated partners all over Europe. The partners are: CEA (France), Chalmers University (Sweden), CIEMAT (Spain), CNR (Italy), CNRS (France), CVR (Czech Republic), ENEA (Italy), Helmholtz-Zentrum Dresden-Rossendorf (Germany), INR (Romania), JRC (European Commission), KIT (Germany), KTH (Sweden), NCBJ (Poland), NRG (Netherlands), PSI (Switzerland), SCK-CEN (Belgium), Slovak University (Slovakia), UKERC (United Kingdom), and VTT (Finland). The associated members are: Aalto University (Finland), CSM (Italy), EDF (France), IFE (Norway), IMDEA Materials (Spain), MPA Stuttgart (Germany), NNL (United Kingdom), Politecnico di Torino (Italy), University of Alicante (Spain), Université libre de Bruxelles (Belgium), University of Helsinki (Finland), University of Genova (Italy), Universitat Politècnica de Catalunya (Spain).

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The building accommodating the Karlsruhe Tritium Laboratory (TLK).

On the way to fusion power

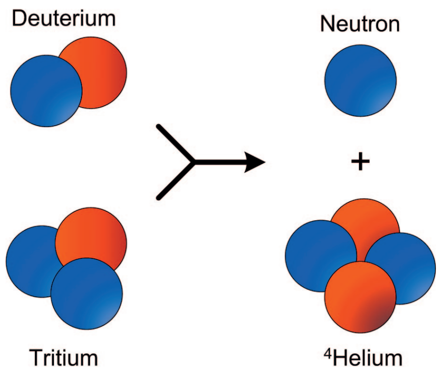
Relying on 20 years of experience from the construction and operation of the Karlsruhe Tritium Laboratory (TLK), KIT is ready to contribute to the procurement of the fuel cycle of the international experimental fusion reactor ITER and the preparation of the next fusion reactor DEMO.

The fusion reaction of the radioactive hydrogen isotope tritium with the hydrogen isotope deuterium is considered to be the most feasible path towards fusion energy on earth. As this fusion reaction produces about 17 MeV of energy, 500 grams of tritium per day would be enough to power a fusion reactor of 1 GW electrical output. However, since the fusion reaction cannot proceed completely in plasma, a closed tritium loop is required to recycle and purify the unburnt fuel for its re-injection into the reactor. Developing the necessary tritium technology and demonstrating its safe operation were the primary motivations to set up the Karlsruhe Tritium Laboratory (TLK).

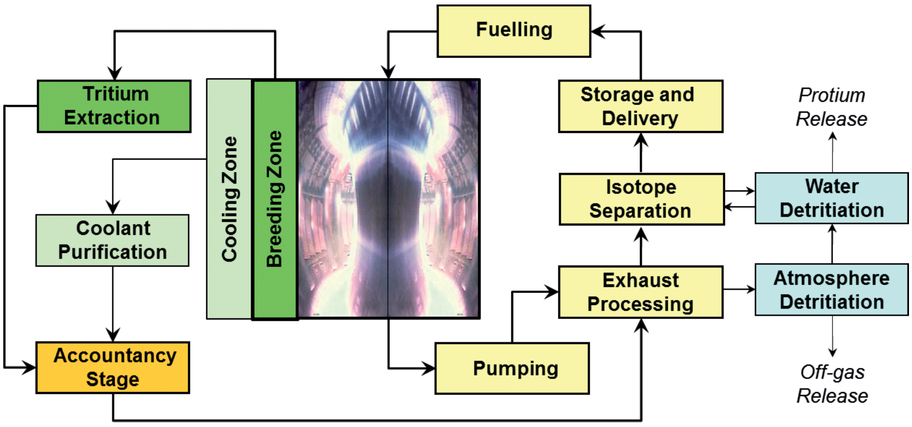
TLK was established in 1993. After it had been granted a first licence to handle up to ten grams of tritium, the laboratory received the first tritium delivery from Canada. In 1996, the TLK tritium loop was closed by the first isotope separation and the tritium storage systems, and the limit defined by the license was increased up to 40 grams. Intense research and development activities under many European task agreements and international cooperation projects followed. Major advances were achieved in practically all parts of the tritium fuel cycle, i.e. measuring tritium retention in plasma-facing components, demonstrating the required detritiation performances for the tokamak exhaust processing, and developing a broad analytical portfolio for accurate and reliable tritium measurements. By 2001, TLK had produced the first conceptual design of most of the sub-systems of the tritium plant for the international experimental fusion reactor ITER.

During the second TLK decade, all these aspects were further developed and deeply consolidated. In particular, the TRENTA facility as pilot plant for the combination of water detritiation with isotope separation was extended gradually in order to support Europe in procuring these sub-systems for ITER. More recently, TLK successfully tackled the missing research and development on highly tritiated water as critical issue for the safe operation of ITER, revealing promising results for two different process candidates. Last but not least, huge efforts were dedicated to developing and optimising advanced analytical methods based on laser-Raman spectroscopy and beta-induced X-ray spectroscopy. Significant improvements of these online and real-time measurement techniques in terms of sensitivity and accuracy will make them essential in the future. All recent successes were only possible because many students were involved – up to 20 at the same time –, thus fulfilling the education mission of KIT.

In the course of 20 years of operation with tritium, all safety systems were fully maintained in operational state, and neither a dose for a worker nor an excessive tritium release into the environment had to be reported. The original TLK safety concept proved to be highly capable and robust. Many of the sub-systems underwent several upgrades to cover moving and extending R&D targets. After having fulfilled their scientific missions, some key installations can now be advantageously used to support the next tritium challenges at TLK.



The deuterium-tritium reaction is considered to be the most feasible path towards fusion energy on earth.



Schematic block diagram and main functions of sub-systems in the entire fuel cycle of a fusion reactor.

The main experimental hall of TLK with several glove boxes for experiments using tritium.

From 2016, the Karlsruhe Tritium Neutrino Experiment KATRIN will operate its tritium source nonstop over several months under extremely stable conditions at an unprecedented tritium throughput. The full TLK tritium infrastructure will be heavily used and at least 20 grams of tritium will be required to fulfil this mission.

And since ITER will consume almost all the worldwide tritium reserves, the next-generation DT fusion reactors, and DEMO at first, are to demonstrate their tritium self-sufficiency by using a so-called breeding blanket, where tritium is produced by the reaction of fusion neutrons with lithium. TLK intends to set up several new experiments in order to test and demonstrate safe and economically viable technological solutions to extract tritium from different breeding blanket concepts, which likely is the most challenging issue for tritium on the way to the deuterium-tritium fusion energy.

Parallel to these two major R&D lines, further efforts will be devoted to other key tritium issues, such as demonstrating different strategies minimising tritium releases into the environment, and developing the technical solutions for efficient waste detritiation techniques. Both aspects are essential for public acceptance of fusion as a future clean and safe nuclear energy. All the upcoming activities are of strategic importance. They will increase TLK's visibility and strengthen its worldwide leadership, while arousing the interest of potential industrial partners that will definitively play an increasing role along the path towards fusion energy.

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The bioliq® pilot plant at KIT. (Markus Breig).

Fruitful German-French cooperation

The cooperation between KIT and the French Alternative Energies and Atomic Energy Commission (CEA) has a long tradition. In the 1950s, a predecessor institution of KIT started to collaborate with the CEA in the field of nuclear energy. In recent years, the partners extended their cooperation to cover various fields of energy research, climate and environment research, materials research, and nanotechnology. "The CEA is our most important European partner in energy research", says Dr. Karl-Friedrich Ziegahn, KIT Head of Division, Energy Research, Earth and Environment Science, Construction Engineering, and Architecture. "Core areas of the cooperation include nuclear energy, fusion technology, and climate protection. An important subject of relevance to the future is technology transfer from nuclear to renewables, e. g. using liquid metal loops as heat carriers in solar thermal plants."

Based in ten research centres in France, the CEA works in four main areas: low-carbon energies, defence and security, information technologies, and health technologies. The CEA is a public body. In 2012, it had a total workforce of 15 867 employees and a budget of 4.3 billion euros. In the field of biofuels, the CEA research centre in Grenoble collaborates with the KIT Energy Center. This cooperation was initiated in 2011 and covers subjects concerning recovery of minerals from non-combustion processes, analytical experiments, modelling, validation, re-use, and market issues. Other subjects shall be included in the long term, e. g. chemicals from syngas, energetic integration of processes, and systems analysis/ technology assessment. Furthermore, the partners are investigating opportunities for further cooperation especially in the field of bioenergy. Both institutions run major project activities in this field. KIT, amongst other things, has developed and installed the bioliq® pilot plant which has been designed to demonstrate technologies in a semi-technical scale for the conversion of biomass like straw and other biogenic residues to high-quality designer fuels and chemical building blocks.

In terms of fusion technology, both KIT and the CEA are involved in the international nuclear fusion research and engineering project ITER. The experimental fusion reactor is being built adjacent to the Cadarache facility, a research centre in the South of France operated by the CEA. Furthermore, KIT and CEA belong to the European Energy Research Alliance (EERA) and participate in various programmes. Within the framework of KIC InnoEnergy, a European alliance of companies, research institutes, universities, and business schools fostering the integration of education, technology, business, and entrepreneurship, KIT and the CEA cooperate in several fields of energy research.

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A high-level training programme in nuclear technology

The demand for experts in nuclear energy is high and continues to increase. Many countries are developing new nuclear power programmes. In Germany, specific expertise will be needed even after the nuclear phase-out – for dismantling and decommissioning of nuclear power plants, but also for medical applications. Furthermore, Germany needs to keep on participating in the international dialogue on nuclear energy.

In order to maintain its comprehensive nuclear competence and to provide excellent education, KIT has formed an alliance with a major industrial partner, AREVA. In 2009, KIT and AREVA founded the AREVA Nuclear Professional School, which offers a high-level training programme covering the complete nuclear technology scope. In July 2013, the partners announced the continuation of the successful programme for another five years.

The AREVA Nuclear Professional School is based at KIT and associated to the Institute for Nuclear and Energy Technologies (IKET). Included in the teaching staff are professors and senior scientists of KIT, of the Technical Universities of Stuttgart and Munich as well as universities abroad, all enjoying excellent reputation. Experienced AREVA employees participate as lecturers. As part of the cooperation, AREVA sponsors doctoral theses and an endowed professorship at the KIT. Combining scientific and industrial aspects, the programme addresses both young scientists and engineers with professional experience in mechanical engineering, process engineering or physics, who intend to specialise in nuclear technology.

For young engineers, the AREVA Nuclear Professional School provides a two-year graduate education and a three-year PhD programme. Thesis projects at institutes of KIT are related to pressurised water reactors, boiling water reactors, or innovative light water reactors. Training courses in a variety of subjects like reactor physics, thermal hydraulics, materials science and stress analysis, reactor design, and safety technology complete the programme.

In order to meet the current training needs of the nuclear industry, the AREVA Nuclear Professional School offers compact courses on special nuclear topics, like heat transfer, flow modelling in fuel assemblies, multi-dimensional computational fluid dynamics, thermo-hydraulic stability analysis, light water reactor core design and fuel management, technology and management of the decommissioning of nuclear facilities, and many more. The courses are held at KIT and other universities and research institutes in Germany and abroad.

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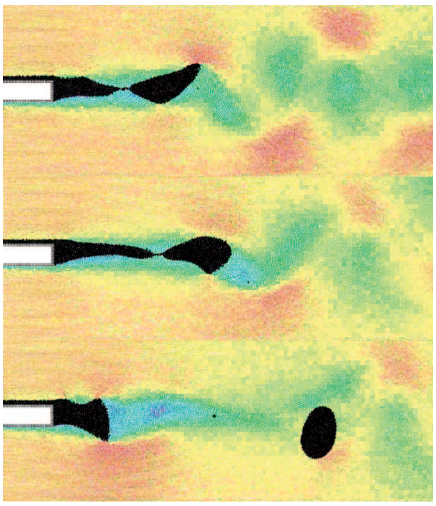
The AREVA Nuclear Professional School addresses young scientists and engineers with professional experience in mechanical engineering, process engineering or physics, who intend to specialise in nuclear technology.

Rolls-Royce University Technology Centre at KIT

In order to achieve the ambitious European climate and energy goals, close cooperation between research and industry is required. The collaboration between the Institute of Thermal Turbomachinery (ITS) of KIT and Rolls-Royce, one of the leading jet engine manufacturers worldwide, can be considered exemplary. In 2007, the ITS was appointed as the fourth German Rolls-Royce University Technology Centre (UTC) and became part of a hand-picked, globe-spanning network that today comprises a total of 31 Rolls-Royce UTCs.

On the one hand, the RR UTC cooperation has fostered a number of joint research projects that were initiated at the ITS to gain a more profound understanding of the processes related to gas turbine fuel preparation, turbine and combustor cooling as well as the secondary air and oil system. On the other hand, the UTC foundation has increased international research collaboration and knowledge transfer between UTCs, for example between the ITS and the University of Nottingham (UK) on oil systems, and between the ITS and the Purdue University (USA) on atomisation processes. Moreover, many KIT postgraduate students and also 35 undergraduate students have benefited from the UTC so far, for example by being enabled to complete a thesis or an industrial placement at one of the Rolls-Royce sites in the UK or in Germany.



Simulation of primary droplet generation in a prefilming airblast atomiser using the so-called smoothed-particle hydrodynamics approach.

Airbus A380, equipped with Rolls-Royce Trent 900 turbofan engines. (This photograph is reproduced with the permission of Rolls-Royce plc, copyright © Rolls-Royce plc 2012.)

One example of the successful research cooperation of the ITS with Rolls-Royce is an ongoing project that deals with the optimisation of aerodynamics and heat transfer in a film-cooled turbine stage using 3D contoured end walls. The objective of this novel approach is to reduce aerodynamic losses of the turbine stage while at the same time improving the cooling efficiency, thus enabling the materials to support even higher turbine entry gas temperatures. To this end, a sophisticated test facility has been set up at the ITS in which heated and pressurised air is sent through a three-blade, film-cooled turbine cascade under conditions similar to those of an engine. Over 250 static pressure taps as well as 2D and 3D laser Doppler anemometry are used to characterise the flow velocities and pressure losses in the test rig. The temperatures on the end wall and turbine blade are measured using long-wave infrared thermography and thermocouples. Based on the temperature data, heat transfer coefficients and cooling effectiveness are determined using inverse finite element analysis.

Further promising progress in cooperation with Rolls-Royce has been achieved in the area of two-phase flow modelling. The optimisation of combustion concepts and oil systems for the reduction of emissions requires the development of more sophisticated simulation tools. At the ITS, the volume of fluid method was successfully enhanced to reproduce droplet-film interactions more realistically. Moreover, an in-house code for the so-called smoothed-particle hydrodynamics was developed and successfully applied to the modelling of film atomisation processes and air-oil interaction in bearing chambers. Compared to expensive experimental studies, the simulation tools provide more detailed information about the flow field and help to gain a profound understanding of the physical processes. The predictions match well with experimental data obtained at the ITS.

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Partnerships down under

Australia has the highest per capita greenhouse gas emissions in the world. The energy sector is responsible for the majority of the emissions. However, Australia has committed to reducing atmospheric pollution. Renewable energies play a strong role in meeting emission reduction targets. The state of Queensland aims to achieve at least 20 per cent renewable energy use by 2020.

As the top-ranked Australian university for power engineering by research income from the Australian Research Council (ARC) and a leading institution in the field of energy research, the Queensland University of Technology (QUT) in Brisbane has tackled a wide range of projects on renewable energy technologies, power converters, energy efficiency, energy delivery, and integrated energy systems and modelling. The energy research centre of QUT resembles the KIT Energy Center in structure and topics. For several years now, there has been a partnership between KIT and QUT with a focus on energy research.

Ongoing and planned cooperative energy research projects between KIT and QUT cover the following subjects: engine combustion modelling, simulation and measurement for alternative/renewable fuels; treatment of wastes of biocommodities by gasification, carbonisation, liquefaction, and combustion; superconducting components and devices; high-voltage transformer testing; data and control processes in smart homes/demand side management; automated network reconfiguration; building science and building physics; microclimates in urban environments; building energy tools; performance data on buildings; decision support in urban environments; agent-based modelling. The QUT Mackay Renewable Biocommodities pilot plant, a research and development facility for the conversion of cellulosic biomass into renewable transport fuels and high-value biocommodities, is comparable to the bioliq® plant of KIT.

Recently, KIT established a partnership with the University of Queensland (UQ), also in Brisbane. UQ, Tianjin University (China), and KIT are planning to set up an "International Centre for the Exploitation of Subsurface Fires". These fires are a major problem in Australia, China and numerous other countries. They can originate from mining operations, but also occur naturally. Propagation and fuel consumption are very slow, so the fires can last for centuries and can cover very large areas. As they affect the availability of resources, cause large perturbations in the global atmospheric chemistry, and present a long-term safety hazard to local populations, subsurface fires are a problem of major environmental concern and, thus, a highly relevant subject for collaboration. A two-day symposium on this subject is planned to take place in February 2014 in Brisbane to initiate collaboration between the partners. Topics will be subsurface combustion, water issues, rock mechanics and heat transfer, measurements, control and extinguishing (or energy harvesting), and environmental issues.

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QUT Gardens Point Campus in Brisbane's city centre, near the Brisbane River.

City centre of Brisbane, the capital and most populous city in the state of Queensland, Australia.

Looking forward to 2015!

The ENERGY, SCIENCE & TECHNOLOGY – International Conference and Exhibition that will take place from May 20 – 22, 2015 in Karlsruhe/ Germany will provide a platform for presenting the most recent results of energy research. KIT is the scientific partner of the EST 2015.

In order to establish a sustainable, reliable and achievable energy system, world-wide cross-linked efforts in research, development and innovation by both the scientific community and the industry are required. At the ENERGY, SCIENCE & TECHNOLOGY – Conference and Exhibition at the Karlsruhe Kongresszentrum, researchers and engineers from all over the world will meet to present the most recent research results, to discuss current and future developments of energy systems, and to exchange information and opinions.

The EST focuses on three major challenges in energy research: sustainable and safe energy production by using renewable energy sources, reducing the need for energy by using energy-efficient technologies, and storage and distribution of energy in complex and flexible energy systems and grids.

All addressed thematic fields are thoroughly approached from different points of view by science and industry. Political and economic discussions complete the holistic approach. The conference is accompanied by a rich exhibition of companies presenting their latest developments and solutions for the prospective, sustainable and safe energy system. The EST is organised by Karlsruhe – Messen und Kongresse.

www.est-conference.com

Wolfgang Breh
Dominique Sauer

Renewable energy

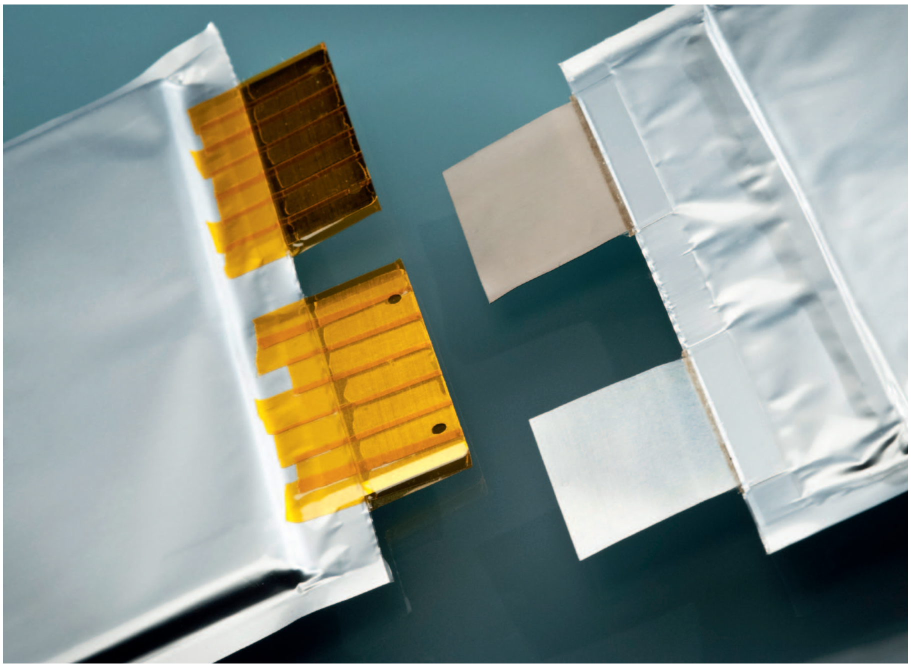
- Inorganic and organic photovoltaics
- Concentrating solar thermal technology
- Energy from chemical and solar fuels
- Energy derived from biomass
- Geothermal energy systems
- Wind energy

Energy efficiency

- Efficient use of fossil and synthetic fuels
- Efficient and flexible power plants
- Enhancement of efficiency in energy conversion
- Energy-efficient buildings
- Efficiency in cooling and heating

Energy systems and grids

- Electrical, chemical and electro-chemical storage of electric energy
- Mechanical storage of electric power and energy-carrying media
- Thermal energy storage
- Electrolysis and hydrogen
- Synthetic fuels
- Electric grids and network integration on all levels
- Gas and fuel grids



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